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CHAPTER 8

SHEATHS, JACKETS, AND ARMORS

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1. SHEATHS

The terms "sheaths" and "jackets" are frequently used as though they mean the same portion of a cable. Sheath is properly the term that applies to a metallic component over the insulation of a cable. An example is the lead sheath of a paper insulated, lead-covered cable. See the definition of jacket in 2.0 below.

Various metals may be used as the sheath of a cable such as lead, copper, aluminum, bronze, steel, etc. A sheath provides a barrier to moisture vapor or water ingress into the cable insulation. It is necessary to use such a sheath over paper insulation, but it also has a value over extruded materials because of water ingress.

The thickness of the metal sheath is covered by ICEA and AEIC standards and specifications, but there are some constructions that are not covered. The thickness is dependent on the forces that can be anticipated during the installation and operation of the cable. Designs range from a standard tube to ones that are longitudinally corrugated. The bending radius of the finished cable is dependent on such configurations.

To fully utilize the metal chosen, one should consider first cost, ampacity requirements -- especially during fault conditions, and corrosion [8-1].

2. THERMOPLASTIC JACKETS

The term jacket should be used for nonmetallic coverings on the outer portions of a cable. They serve as electrical and mechanical protection for the underlying cable materials.

There are many materials that may be used for cable jackets. The two broad categories are thermoplastic and thermosetting. For each application, the operating temperature and environment are important factors that must be considered.

2.1. Polyvinyl Chloride (PVC)

PVC is the most widely used nonmetallic jacketing material in the wire and cable industry. Starting in 1935, when it first became available, the use of PVC grew rapidly because of its low cost, its easy processing, and its excellent combination of overall properties including fire and chemical resistance.

PVC belongs to a group of polymers referred to as vinyls. The unmodified polymer contains approximately 55 % chlorine. It is fairly linear in structure (few side chains) with approximately 5 to 10 % crystallinity. The material must be compounded with additives such as fillers, plasticizers, and stabilizers to attain flexibility, heat resistance, and low temperature properties. General purpose jacketing materials normally possess good physical strength, moisture resistance, adequate oil resistance, good flame resistance and excellent resistance to weathering and to soil environments. Flame resistance and low temperature flexibility can both be improved within limits by the use of additives.

General purpose PVC compounds are recommended for installation at temperatures above -10 °C, but specially formulated compounds may be used as low as -40 °C.

One of the limitations of PVC jacketed cable is its tendency to creep under continuous pressure. For this reason, cables which are to be supported vertically with grips should not have PVC jackets. Hypalon or neoprene are recommended for such use.

In the low voltage field, PVC is widely used as a single layer of material where it functions both as insulation and jacket. Since PVC is a thermoplastic material, it cannot take high temperatures. Under high current fault conditions the insulation can be permanently damaged by melting or can emit plasticizers and become stiff and brittle. For this reason, it is not used as utility secondary network cable. Similarly, in industries that handle large amounts of heated material, or where there is the possibility of excessive heat, the use of PVC is avoided because of its tendency to melt or deform when heated to a high temperature. Under continuous dc voltage in wet locations, as in battery operated control circuits, single-conductor PVC-insulated cables have frequently failed due to electro-endosmosis (water vapor ingress created by voltage stress).

The large percentage of chlorine can be released during a fire. When combined with moisture, hydrochloric acid may be produced. This situation highlights one of the major problems that can result from the use of PVC.

2.2 Polyethylene

Polyethylene (PE) has been widely used as a jacket for underground cables since it became commercially available in large quantities in about 1950. For use as a jacket, polyethylene may be compounded with carbon black or coloring material, and with stabilizers. Carbon black gives the material the necessary sunlight protection for outdoor use.

Polyethylene for jacketing is categorized under three different densities:

Low density	0.910 to 0.925 grams per cm ³
Medium density	0.926 to 0.940 grams per cm ³
High density	0.941 to 0.965 grams per cm ³

Density generally affects the crystallinity, hardness, melting point, and general physical strength of the jacketing material. In addition to density, molecular weight distribution is important since it influences the processing and properties of the polymer.

Polyethylene jackets are an excellent choice where moisture resistance is a prime design criteria since it has the best moisture resistance of any non-metallic jacket material. When polyethylene is used as a jacket material, it should be compounded with enough carbon black to prevent ultra-violet degradation. Linear, low density, high molecular weight (LLDPE) is the most popular jacket material since it has better stress-crack resistance than the high density materials. High density provides the best mechanical properties, but may be very difficult to remove from the cable.

In evaluating fillers, both black and non-black, it has been found that although many of these materials improve the aging characteristics, carbon black is by far the best. It has also been found that the aging resistance increases with carbon black loading from 2 to 5 percent. Normally, a 2.5 to 3.0 percent loading is used.

Although PE has good moisture resistance and good aging properties in its temperature limits, it has poor flame resistance. This discourages using it as a jacket in many circumstances. Polyethylene jackets have good cold bend properties since they will pass a cold bend test at about -55 °C. They are extremely difficult to bend at low temperature because of their stiffness. Like PVC, PE is a thermoplastic material and will melt at elevated temperatures. This temperature will vary slightly with molecular weight and density, but melt occurs at about 105 °C.

High density polyethylene (HDPE) has been used extensively as the second (outer) layer for "ruggedized" thermoplastic in secondary and low voltage street

light cables because of its toughness.

While black polyethylene for jacketing is frequently an insulating material, with higher loadings of carbon-black it can be a semiconducting material. This material has been used for over 30 years in direct-buried applications to improve the grounding of the concentric neutral.

2.3 Chlorinated Polyethylene (CPE)

CPE can be made either as a thermoplastic or as a thermosetting jacket material. As a thermoplastic material, it has properties very similar to PVC, but with better higher temperature properties and better deformation resistance at high temperatures than PVC. CPE jackets also have better low temperature properties than PVC unless the PVC is specifically compounded for this property.

2.4 Thermoplastic Elastomer (TPE)

TPE is a thermoplastic material with a rubber-like appearance. It is a form of crystalline polyethylene and it comes in various types. It can be compounded for use as either an insulation or a jacketing material. By use of compounding techniques, a good electrical insulation can be developed with good moisture resistance properties.

Also, a jacketing material can be compounded to provide flame resistance, low temperature performance, good abrasion resistance, and good physical properties. This material is relatively new as compared to the thermoplastics previously mentioned, but appears to be a very versatile material.

2.5 Nylon

Nylon is a thermoplastic with many properties which make it desirable for jacketing of wire and cable. Nylon has relatively high strength, tough, but rather stiff especially in cold weather. Nylon also has good impact fatigue and, within limitations, good abrasion resistance. A very important feature is the low coefficient of friction in contact with conduit materials. This is an aid in pulling cables into conduits. Nylon has excellent resistance to hydrocarbon fuels and lubricants as well as organic solvents. However, strong acids and oxidizing agents will attack nylon. The most common use of nylon in cable jacketing is the jacket on THHN and THWN building wire.

3. THERMOSETTING JACKETING MATERIALS

Thermosetting jackets are not widely used for underground distribution cables except for the special case of medium- or high-density crosslinked polyethylene

that is used as the outer layer on two layer, "ruggedized", secondary cables. Thermosetting jackets are more commonly utilized in industrial and power plant applications.

3.1 Crosslinked Polyethylene

Crosslinked polyethylene, with the addition of carbon black to provide sunlight resistance, provides a tough, moisture, chemical, and weather resistant jacket material. The medium and high density materials are especially tough and are widely used as the outer layer on two layer "ruggedized" secondary cables. Only limited use is found for other purposes.

3.2 Neoprene

Neoprene has been used as a jacketing material since 1950 for large power cables such as paper insulated, lead-covered cables and portable cables. Compounds of neoprene usually contain from 40 to 60% by weight of neoprene that is compounded with other ingredients to provide the desired properties such as good heat resistance, good flame resistance, resistance to oil and grease, and resistance to sunlight and weathering. Moisture resistance can be compounded into the material when required.

Properties that can be varied by compounding techniques are: improved low temperature characteristics, improved physical strength, and better moisture resistance. Most Neoprene compounds have good low temperature characteristics at -30 °C to -40 °C. Special compounding can lower this to -60 °C, but other properties, such as physical strength, have to be sacrificed.

Because of its ruggedness, tear resistance, abrasion resistance, flame resistance, and heat resistance, neoprene is the most widely used jacketing material for the mining industry. This is probably the most severe application for cables from a physical standpoint. The thermosetting characteristics of neoprene are desirable in this application since these cables must withstand high temperature while installed on cable reels. Thermoplastic jacketing materials would soften and deform under such environments.

3.3 Chlorosulphanated Polyethylene (CSPE)

CSPE is a thermosetting jacket compound with properties very similar to neoprene. CSPE is unique in that colored compounds of this material, protected by sunlight stable pigments, have weather resistant properties similar to black CSPE compounds. Hypalon is the trade name of the most commonly used material.

CSPE compounds are superior to neoprene compounds in the areas of resistance to heat, oxidizing chemicals, ozone, and moisture. They also have better dielectric properties than neoprene. The flame resistance of both materials is excellent. The superior heat resistance of CSPE as compared with neoprene, makes it the better choice for cables rated at conductor temperatures of 90 °C.

3.4 Nitrile Rubber

Nitrile rubber compounds are copolymers of butadiene and acrylonitrile. They provide outstanding resistance to oil at higher temperatures. Since this is their only outstanding feature, they are generally limited to oil well applications where temperatures up to 250 °C can be encountered. Their poor oxidation resistance in air limits their use for other applications.

3.5 Nitrile-Butadiene/Polyvinyl Chloride

These jacket compounds are blends of nitrile rubber mixed with PVC to provide a thermosetting jacket similar to neoprene. The advantage of this material over neoprene is that colored jackets of NBR/PVC have properties comparable to black jackets and can be compounded for physical properties and tear resistance similar to that of neoprene.

3.6 Ethylene Propylene Rubber

EPR is frequently used as an insulating material because of its balance of outstanding electrical properties. They can also be used for jackets, especially in low temperature applications where flexibility is required. These materials can be compounded for -60 °C applications with reasonably good physical properties and tear resistance.

EPR is not generally used for a jacketing material in other applications. They are used as jackets in low voltage applications when flame resistance has been compounded into the material.

4. ARMOR

4.1 Interlocked Armor

This armor consists of a single metal tape whose turns are shaped to interlock during the manufacturing process. Mechanical protection is therefore provided along the entire cable length.

Galvanized steel is the most common metal provided. Aluminum and bronze are used where magnetic effects or weight must be considered. Other metals, such

as stainless steel or copper, are used for special applications.

Interlocked-armor cables are frequently specified for use in cable trays and for aerial applications so that conduit and duct systems can be eliminated. The rounded surface of the armor withstands impact somewhat better than flat steel tapes. The interlocked construction produces a relatively flexible cable that can be moved and repositioned to avoid obstacles during and after installation.

An overall jacket is often specified in industrial and power plants for corrosion protection and circuit identification. Neither flat-taped armor or interlocked armor is designed to withstand longitudinal stress, so long vertical runs should be avoided.

4.2 Round-Wire Armor

This construction consists of one or two layers of round wires applied over a cable core. For submarine cable applications, the wires are usually applied over a bedding of impregnated polypropylene or jute.

Round-wire armor is used where high tensile strength and resistance to abrasion and mechanical damage are desired. Vertical riser cables and borehole cables are made with round-wire armor when end-suspension from the wires is necessary for support for the longitudinal stresses. Round wires have less resistance to piercing than flat-tape armor or interlocked armor, but has superior tensile strength and abrasion resistance.

For single-conductor cables, copper or aluminum wires have been used to minimize losses due to circulating currents. Such constructions sacrifice mechanical strength in order to achieve the lower losses.

Armor wires can be made with the individual wires coated with polyethylene or other corrosion resistant coverings. Since there is a portion of the circumference without metal protection, cables with such covered wires are usually made with two layers of armor wires with the second layer in the opposite lay to the first.

For installations in severe rock environments, two layers of steel wires, with no individual coverings, are applied in reverse lay. The outer layer frequently is applied with a very short lay to achieve optimum mechanical protection.

The number of armor wires for a wire-armored cable may be calculated from the following equation:

$$N = \left[\frac{\pi (D + d)}{Fd} \right] - 2 \quad (8.1)$$

where N = Number of armor wires, nearest whole number
 D = Core diameter of cable under armor in inches
 d = Diameter of armor wire in inches
 F = Lay factor. See Table 6.2.
 $D + d$ = Pitch diameter of armor wire in inches

Armor resistance may be calculated from the following equation:

$$Ra = \frac{r_a \times F}{1,000 N} \quad (8.2)$$

where r_a = dc resistance of one armor wire or tape per 1,000 feet at temperature t in ohms
 F = Lay factor. See Table 8.2.
 N = Number of armor wires

Note: For steel wire armor, increase Ra by 50% to obtain approximate ac resistance.

Table 8-1
Approximate dc Resistance of Armor Wire

Wire Size	Wire Diameter	Galvanized Steel	Hard Drawn Copper	Commercial Bronze
BWG	inches	ohms per 1,000 feet	ohms per 1,000 feet	ohms per 1,000 feet
12	0.109	7.33	0.895	2.49
10	0.134	4.92	0.592	1.65
8	0.165	3.16	0.391	1.09
6	0.203	2.12	0.258	0.72
4	0.238	1.53	0.188	0.52
Basis:				
Conductivity,	% IACS	12.0	97.5	40.0
Temperature Coefficient of Resistivity	(α)	0.0035	0.00383	0.00190

Table 8-2
Lay Factor for Round Wire Armor

Ratio of Length of Lay to Pitch Diameter of Armor Wire	Lay Factor
7	1.095
8	1.072
9	1.057
10	1.048
11	1.040
12	1.034

Note: Use 7 as a typical value if the ratio is unknown.

5. REFERENCE

[8-1] Carl C. Landinger, Adapted from class notes of the *Power Cable Engineering Clinic*, University of Wisconsin-Madison, October, 1997.